Upper Menominee River Regional Curve

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Abstract.-Regional curves provide a better understanding of river morphology and help in the design of stream restoration projects by providing information to estimate bankfull discharge, mean depth, width, and cross-sectional area at ungaged sites within given watersheds. Although regional curves have been developed for various United States watersheds, a statewide effort to develop regional curves is only recently underway in Michigan. In July and August 2006, data were collected to develop regional curves for the Upper Menominee River watershed, based on bankfull characteristics of the Sturgeon River, Iron River, Brule River, Pine Creek, and Peshekee River. Data collected on each water body included surveys of longitudinal and cross-sectional profiles, and measurement of channel materials. Analysis of the data determined bankfull channel dimensions and allowed for reaches to be classified according to Rosgen stream types. Using the surveyed data, regional curves were developed from regression analyses of the relationship between bankfull channel dimensions and watershed drainage area. Bankfull cross-sectional area and depth have the strongest relation to drainage area as evidenced by R^2 values of 0.78 and 0.74, respectively. Although the number of surveyed sites was small, these curves may be used as general guidelines to help ensure proper design and stability of future stream channel modifications and restoration efforts in the Upper Menominee River watershed.

Introduction

There is growing interest in restoration of stream channels impacted by excessive sedimentation, erosion, or otherwise degraded habitat. Accompanying this interest is a trend for managers to design projects that utilize a natural channel approach, with the goal of rebuilding a channel with the proper dimensions, slope, and pattern that allow for the transfer of water and sediment loads from the drainage basin without aggradation or degradation of the stream bed. Projects employing natural channel design are often based on bankfull channel measurements. The bankfull channel is formed by the bankfull discharge, defined by Dunne and Leopold (1978) as the discharge at which channel maintenance is the most effective at moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels. Characteristics of the bankfull channel, including bankfull cross-sectional area, width, and mean depth, are strongly correlated with watershed drainage area (Dunne and Leopold 1978).

To facilitate the design of natural channel projects, many states and federal entities have contributed to development of regional curves. Regional curves, which are regressions of the relationships between bankfull channel characteristics and watershed drainage area, are used to define bankfull characteristics without additional data collection or analysis. Most commonly, a regional curve may be used to estimate bankfull channel dimensions and discharge at un-gaged reaches within the same watershed or within watersheds having similar characteristics.

The purpose of this project was to produce regional curves for the Upper Menominee River watershed based on bankfull channel dimensions and drainage basin characteristics. The Upper Menominee River watershed regional curves may be used as general guides for restoration designs within the same watershed by providing information on the correct channel dimensions to accommodate stream flow and sediment load. Information collected from the Upper Menominee River will be included in a larger morphological database of Michigan's regional curves for use by federal, state, and local agencies.

Methods

Study Sites

For the purpose of this study, the geographic scope of the Upper Menominee River basin includes the area encompassing the Michigamme River from the Michigamme Reservoir backwater to the confluence with the Brule River, the Paint and Brule rivers from upstream of the Lower Paint impoundment down to the confluence with the Michigamme River, and the Menominee River from its source to the backwater of the Chalk Hill hydroelectric project (Figure 1). Within the basin are 56 dams, 19 of which are hydroelectric dams. The Menominee River, formed by the confluence of the Brule and Michigamme rivers, flows about 114 mi through generally forested land into Green Bay at the cities of Marinette, Wisconsin and Menominee, Michigan. Other than the cities of Iron Mountain and Kingsford and several rural towns and villages, the Upper Menominee River Basin is sparsely populated (Wisconsin Electric Power Company 1999).

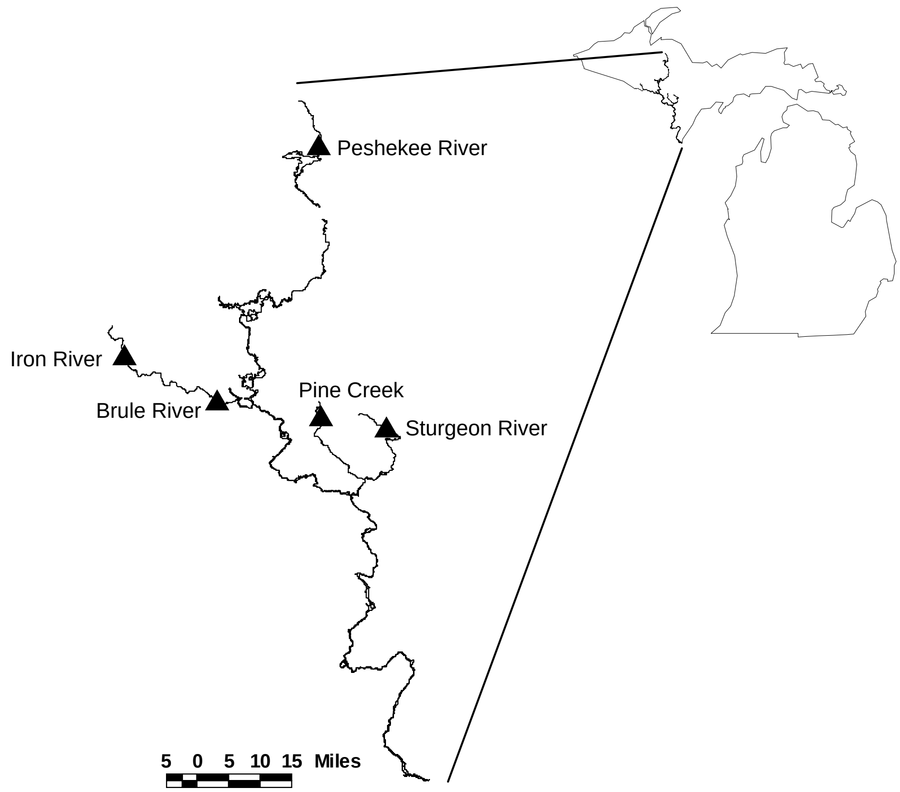

Figure 1.-Map of the Upper Menominee River watershed, Michigan, showing the locations of the selected study sites used for development of regional curves.

Study sites were selected at U.S. Geological Survey (USGS) gage stations that met the minimum criteria of having at least 10 years of record, a recoverable benchmark referenced to the gage datum, no influence by dams or artificial control structures, and the ability to be safely waded for a length of 20 bankfull widths or two meanders. Station descriptions from the USGS and field reconnaissance were used to determine which study sites met the minimum criteria.

Of the 21 potential sites in the Upper Menominee River watershed that had at least 10 years of gage datum, only five sites met all of the selection criteria (Table 1). Many sites were not appropriate because they were either influenced by hydropower dam operations or were too large to be safely waded.

Table 1.-Streamflow gaging stations used for development of regional curves for the Upper Menominee River watershed, Michigan. [dms= degree, minutes, and seconds]

U.S. Geological Survey station number	Station name	Latitude (dms)	Longitude (dms)	Period of record used for analysis
04060500	Iron River at Caspian, MI	46 03 31	88 37 38	1948-1983, 2004-2006
04060933	Brule River near Florence, WI	45 57 39	88 18 57	1993-2006
04065600	Pine Creek near Iron Mountain, MI	45 55 51	87 58 18	1971-1981
04065500	Sturgeon River near Foster City, MI	45 54 30	87 45 15	1954-1980
04062200	Peshekee River near Champion, MI	45 33 25	88 00 09	1961-1978, 2000-2006

Data Collection

Field methods followed protocols established by Michigan's Stream Team (2005). These methods are summarized below. Data were collected during July and August 2006 (Table 2). From the collected morphological data, stream types were assigned according to the stream classification system developed by Rosgen (1994).

Table 2.-Bankfull stream channel characteristics of study sites in the Upper Menominee River watershed, Michigan. [D_{50}= median particle size of streambed material, D_{84}= particle size larger than 84 percent of streambed material]

Study Reach	Iron River	Brule River	Pine Creek	Sturgeon River	Peshekee River
Cross-sectional area (ft^2)	152.2	349.9	87.7	409.6	747.3
Width (ft)	48.8	111.2	46.6	107.1	134.1
Mean depth (ft)	3.1	3.2	1.9	3.8	5.6
Discharge (ft^3/s)	227	1350	48	890	1599
Recurrence interval (years)	1.08	1.75	1	1.22	1.04
D_{50} (mm)	7.9	33.9	0.1	0.8	37.1
D_{84} (mm)	56	362	0.9	14	77
Width:Depth Ratio	15.6	35.3	24.8	28	24.1
Entrenchment Ratio	1.9	3.2	6.9	5.5	3.8
Slope (ft/ft)	0.0028	0.0009	0.0012	0.0002	0.0018
Rosgen stream type	$B4_c$	$C4_{c-}$	C5	$C5_{c-}$	C4

Survey Set-Up

At each gage site, USGS station descriptions, level summaries, and stream rating tables were reviewed along with aerial photographs and plat maps. Reference marks with known elevations were located from the station description and compared with the most recent level notes. After recording the gage datum water surface elevation, the corresponding discharge was determined using the associate USGS rating table. The recurrence interval or average yearly time interval between occurrences of a hydrological event of a given or greater magnitude for this discharge was calculated with formulae provided by Michigan Department of Environmental Quality (2006).

The extent of each study reach equaled at least two full meander lengths or approximately 20 times the bankfull width. The study reaches began and ended on the same type of morphologic feature (e.g., top of riffle to top of riffle). The reaches of the five study sites were waded to lay out the measuring tapes, to identify and record distances for each macrohabitat feature (i.e., run, riffle, pool, glide), and to mark bankfull elevation. The most representative pool and riffle within the study reach were identified visually for cross-sectional surveys.

Surveys for each study site began at the upstream end of the study reach. To reduce the number of times the laser level needed to be moved, the level was set up in a stable location where the reference marks, bankfull indicators, and the thalweg (the transect location with the deepest water depth) could be surveyed both across the river and for a maximum distance downstream. Photographs were taken at each of the five study sites depicting view upstream and downstream of the reach, and both banks at each cross-section.

Longitudinal Profile

The longitudinal profile included measurements taken upstream and downstream within a reach. These measurements determined water surface slope and shape of the channel bed and floodplain. To obtain a longitudinal profile, elevations and positions corresponding to the changing macrohabitat features (run, riffle, pool, and glide) were surveyed. At each pool and riffle cross-section, rebar monuments were installed at least 1 foot beyond bankfull on both sides of the stream and the elevation of the rebar was determined using the laser level. To close the longitudinal profile for each site, the survey ended at the same point where it began to ensure the level set closed within acceptable limits (generally less than 0.02 ft). If measurement accuracy was not within acceptable limits, the longitudinal profile was repeated.

Cross-Section

The cross-section included measurements along a vertical plane perpendicular to the stream to determine channel form. For each of the five study sites, one pool and at least one riffle cross-section were surveyed to provide cross-section data (bankfull width and depth, cross-sectional area, and flood prone width) needed for the regional curve. The cross-sections were established perpendicular to the direction of the flow and extended laterally beyond the bankfull channel. Rebar monuments installed during the longitudinal profile survey were used to lay a measuring tape across the river, with zero starting on the left bank looking downstream. For both the pool and riffle cross-section profile, surveyed points corresponded to top of rebar, ground next to rebar, bankfull, edge of bank, water surface, and thalweg. Flood-prone width was estimated at riffle cross-sections by measuring the distance between the two points of elevation on both sides of the river that correspond to twice the maximum depth of the bankfull channel (Rosgen 1996).

Pebble Count

Pebble counts were conducted throughout the reach and at the riffle and pool cross-sections using the method described by Wolman (1954). The method for picking up pebbles for the pebble count entailed averting one’s gaze and reaching straight down and picking up the first particle touched by the tip of the index finger. The intermediate axis (neither the longest nor the shortest of the three mutually perpendicular sides) of the particle was measured and recorded by size class. For sand and silt, the size class of particles was determined by tactile and visual comparison using a sand gage.

The reach average pebble count characterized the size of bed materials by measuring 100 samples in ten transects distributed through the entire reach according to the proportion of macrohabitat types. For example, if 30 percent of the reach length was pool habitat, and 70 percent was riffle habitat, the corresponding reach average pebble count would include three transects in pools and seven transects in riffles. The riffle and pool pebble counts were conducted by sampling at least 100 particles along the wetted width of the surveyed cross-sections.

Data Analysis

All data were entered into the RIVERMorph software program (RIVERMorph LLC, Louisville, KY). The RIVERMorph program analyzes geomorphic data and facilitates river assessment, monitoring, and design. The RIVERMorph program also has a tool that develops regional curves, or a series of regression lines on a log-log graph of watershed area versus bankfull channel dimensions.

Results

Characteristics of Assessed Stream Reaches

Iron River at Caspian, Michigan- 04060500.-This site was located in SE ¼ and SW ¼ Section 1, T.42N, R.35W, in Iron County on County Road 424, in Caspian, Michigan. The drainage area for this reach was 92.10 mi^2. The longitudinal profile began on downstream side of the bridge on County Road 424 and extended for a reach of 950 ft. The reach ended just above the City of Caspian's waste water treatment plant discharge.

The reach was characterized by low banks with heavy overhanging brush. The bankfull channel was not well defined within the first 200 ft of the reach, owing to the highway bridge, abandoned railroad track, and altered floodplain. Further downstream, bankfull was defined by a subtle change in bank angle and depositional features. A view of the reach is shown in Figure 2.

Figure 2.-View looking downstream at reach for Iron River at Caspian, Michigan.

Brule River near Florence, Wisconsin- 04060933.-This site was located in NW ¼ SE 1/4 Section 9, T.41 N, R32 W, in Iron County on U.S. Highway 2, 4 mi northwest of Florence, Wisconsin. The drainage area for this site was 347.42 mi^2. The longitudinal profile was 1340 ft and began upstream of the U.S. Highway 2 Bridge.

The reach was characterized by a fairly straight channel, riffle habitat, and relatively steep banks. A view of the reach is shown in Figure 3. The bankfull indicators were more easily identified on the left bank by changes in bank angle and riparian vegetation.

Figure 3.-View looking upstream at reach for Brule River near Florence, Wisconsin.

Pine Creek near Iron Mountain, Michigan- 04065600.-This site was located in the SE ¼ SE ¼ Section 19, T41N, R29W, Dickinson County on County Road 866, 9 mi northeast of Iron Mountain, Michigan. The drainage area equaled 16.80 mi^2. The longitudinal profile for the study site consisted of a reach of 555 ft in length beginning upstream of County Road 866.

Much of this reach is characterized by a gradually meandering channel with a prevalence of run habitat. A view of the reach is shown in Figure 4. Bankfull was characterized by a change in bank angle and riparian vegetation.

Figure 4.-View looking upstream at reach for Pine Creek near Iron Mountain, Michigan.

Sturgeon River near Foster City, Michigan- 04065500.-This site was located in the NW ¼ Section 36, T41N, R28W, Dickinson County on County Highway 569, 4 mi south of Foster City, Michigan. The drainage area for this site was 237.00 mi^2. The longitudinal profile included a 1510 ft reach that began on the downstream side of the bridge on County Road 569.

This reach was wide and shallow, with a bottom substrate composed primarily of sand. A view of the reach is shown in Figure 5. The left bank was fairly high and not suitable for bankfull measurements. Most bankfull measurements on the right bank were characterized by depositional features, and a change in bank angle and riparian vegetation.

Figure 5.-View looking downstream for Sturgeon River near Foster City, Michigan

Peshekee River near Champion, Michigan- 04062200.-This site was located in the NW 1/4 Section 13, T 48 N, R 30 W, Marquette County on County Highway 607, 3.5 mi northwest of Champion, Michigan. The drainage area equaled 133.00 mi^2. The longitudinal profile for this site included a reach of 1800 ft in length beginning approximately 100 ft downstream of the bridge at County Road 607, which ran alongside the entire reach length.

To avoid a deep, unwadeable pool, the reach began approximately 100 ft downstream of the gage. There were no tributaries or sources of increased discharge between the gage and the start of the longitudinal profile. Much of this reach was characterized by high banks and coarse gravel and bedrock. A view of the reach is shown in Figure 6. Bankfull indicators included change in bank angle and riparian vegetation.

Figure 6.-View looking upstream at reach for Peshekee River near Champion, Michigan.

Rosgen Stream Types

Of the five streams surveyed and partitioned into Rosgen stream types (Rosgen 1994, 1996), there was one B-type (Iron River) and four C-types (Brule River, Pine Creek, Sturgeon River and Peshekee River). B stream types typify moderately entrenched streams with a moderate gradient, dominated by riffles and characterized by stable banks, and C stream types typify low gradient, meandering streams defined by riffle pool channels and broad, well-defined floodplains (Rosgen 1996). The sub-letter accompanying some stream types, e.g., $B4_c$, indicates that the reach fits into a different stream type according to the measured slope. Both Pine Creek and Sturgeon River were classified as having sand-dominated bed material, while the other rivers were classified as gravel-dominated.

Bankfull Stream Flow

Our results show that bankfull flow events ranged from every 1 to 1.75 years (Table 2). On average, bankfull flows occurred approximately every 1.2 years in the Upper Menominee watershed.

Regional Hydraulic-Geometry Relations

After reviewing the data, it was determined that the Peshekee River lies in a different physiographic region, one that is north of the geographic boundary of the Upper Menominee River watershed. Compared to the Upper Menominee River drainage area, the drainage area of the Peshekee River is characterized by higher and more intense surface runoff and snowmelt events. To provide accurate regional curves for the Upper Menominee River, data from the Peshekee River were not included.

The regional curves for the Upper Menominee River watershed regress drainage area versus bankfull discharge, width, mean depth and area (Figures 7 to 10). The relation between bankfull discharge and drainage area determined for the Upper Menominee watershed, excluding the Peshekee River, is $Q_{bkf} = 12.19\ A^{0.63}$, where Q_{bkf} is bankfull discharge in ft^3/s and A is the drainage area in mi^2. This regression equation has a correlation coefficient R^2 of 0.42. The relation between width (W_{bkf}) in ft and drainage area is $W_{bkf} = 25.35\ A^{0.20}$ ($R^2 = 0.65$), while the relation between mean depth (D_{bkf}) in ft and drainage area is $D_{bkf} = 1.45\ A^{0.13}$ ($R^2 = 0.74$), and the relation between cross-sectional area (A_{bkf}) in ft and drainage area is $A_{bkf} = 36.73\ A^{0.33}$ ($R^2 = 0.78$).

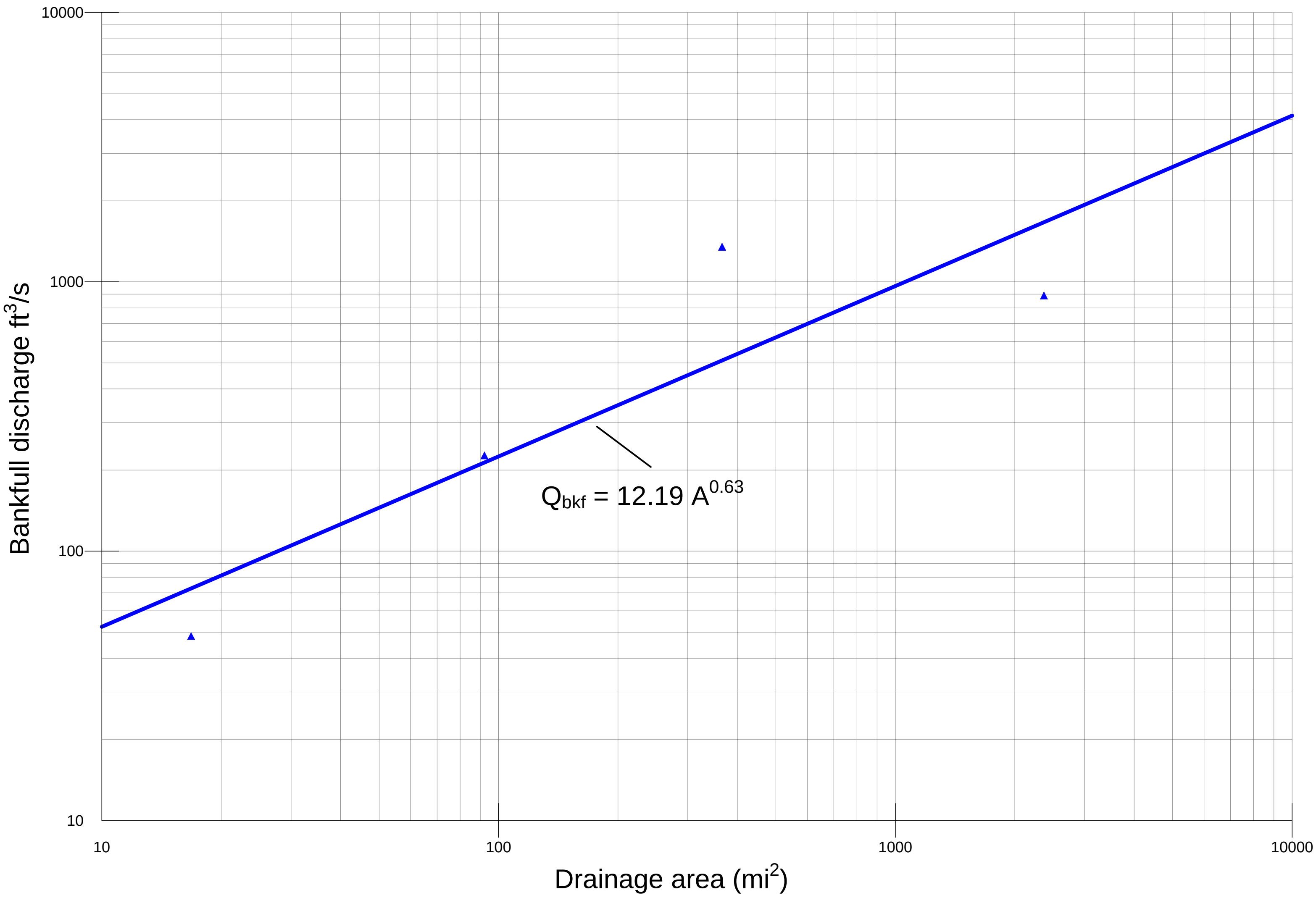

Figure 7.-Regional curve relating bankfull discharge (Q_{bkf}) to drainage area for the Upper Menominee River watershed in Michigan.

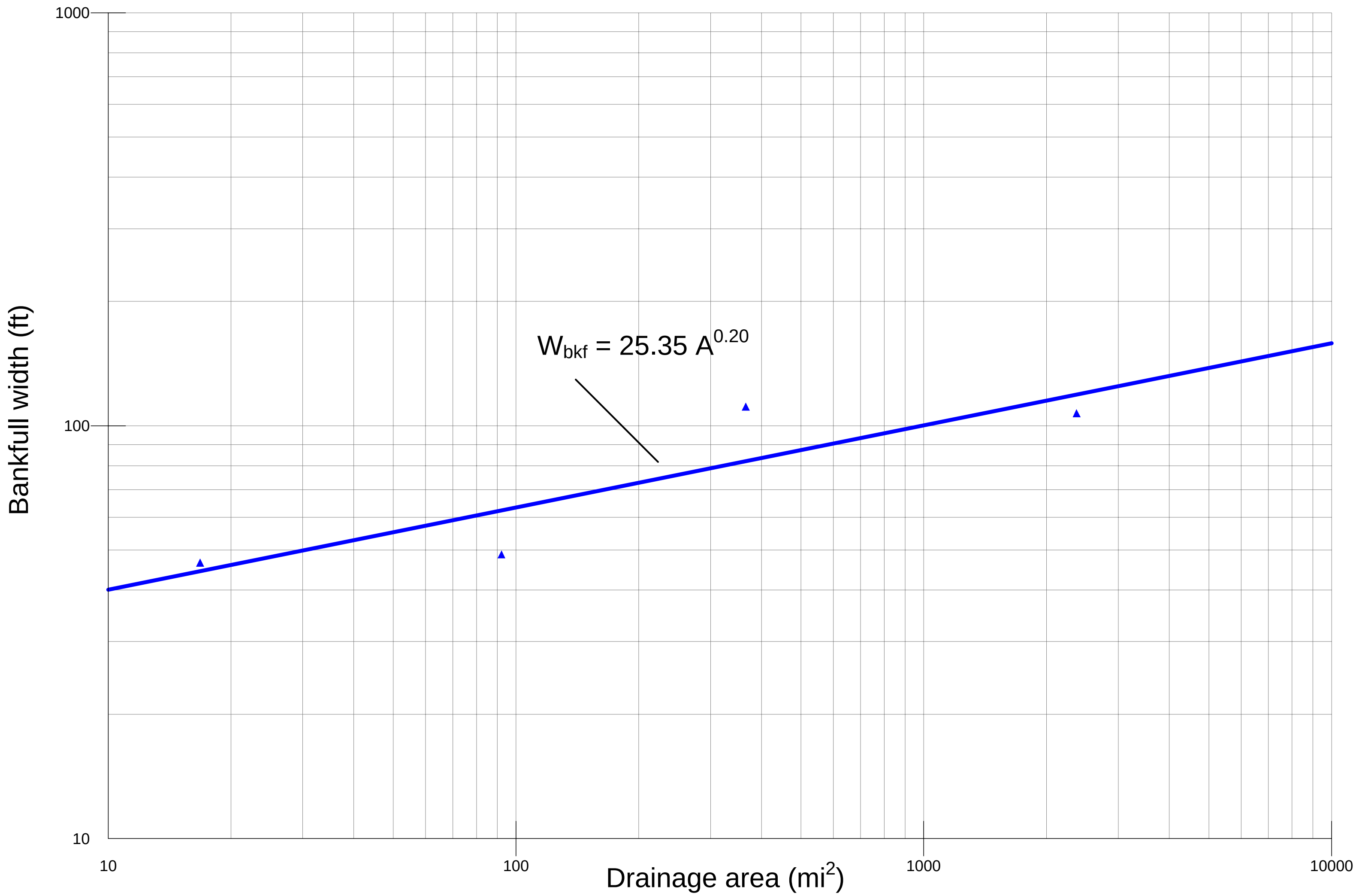

Figure 8.-Regional curve relating bankfull mean width (W_{bkf}) to drainage area for the Upper Menominee River watershed in Michigan.

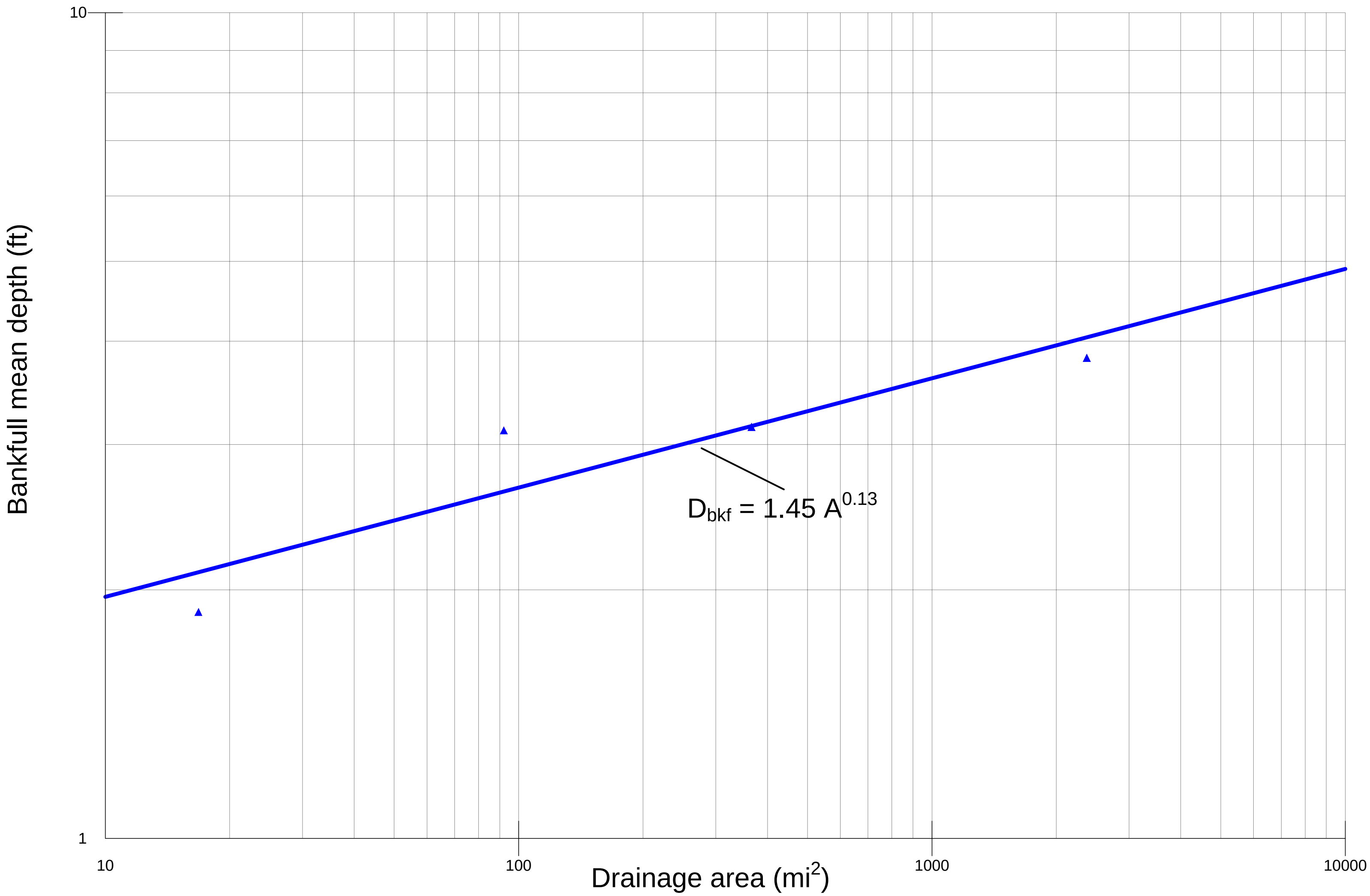

Figure 9.-Regional curve relating bankfull mean depth (D_{bkf}) to drainage area for the Upper Menominee River watershed in Michigan.

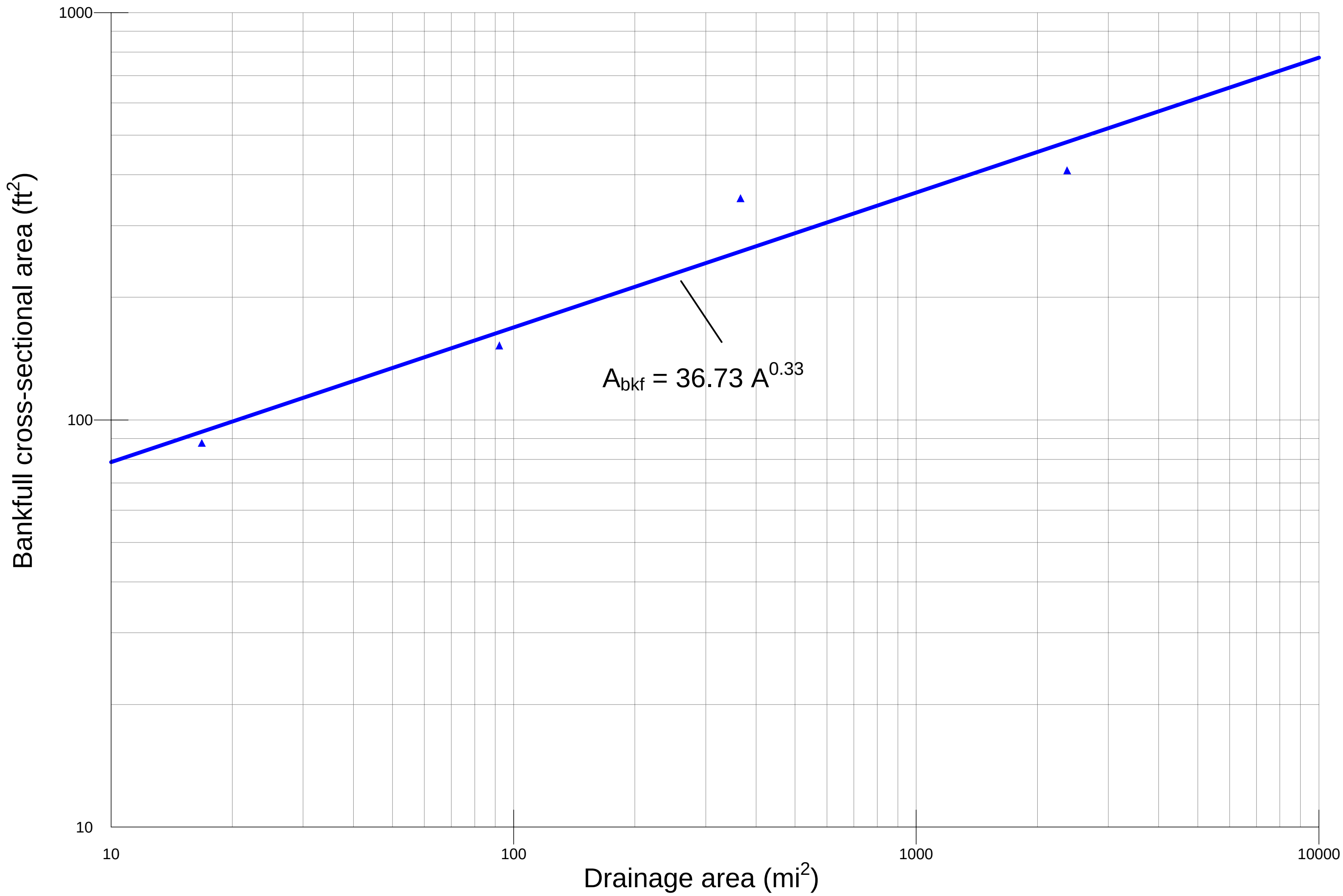

Figure 10.-Regional curve relating bankfull cross-sectional area (A_{bkf}) to drainage area for the Upper Menominee River watershed in Michigan.

Discussion

The purpose of the Upper Menominee River regional curve is to provide a quantitative understanding of the watershed and present the results in a way that is useful for stream restoration projects and assessment of stream health. The data collected for this curve will also contribute to a recently initiated state-wide regional curve project.

The Rosgen stream classification system (1994, 1996) represents a method to predict a river's behavior from its appearance, develop specific hydraulic and sediment relationships, extrapolate data to similar reaches, and provide consistent terms of reference. The number of Rosgen stream types in this study was limited to two (B and C). Although this information is useful for the purposes of predictions and reference, the limited number is insufficient to consider regional relationships by stream type within the Upper Menominee River watershed. Additional data collection within the Menominee River watershed are needed to evaluate regional relationships by stream type.

According to the literature, bankfull discharge occurs every 1.5 years on average in the United States (Emmett 1975; Dunne and Leopold 1978; Leopold et al. 1995). The results from this study show that bankfull discharge in the Upper Menominee watershed ranged between 1 to 1.75 years and tends to occur relatively frequently, or every 1.2 years on average. The increased frequency may be attributed to the flat terrain and easily distinguishable floodplains of the watershed.

Bankfull channel dimensions of cross-sectional area, width, mean depth, and the related streamflow velocities tend to increase linearly with increases in drainage area (Leopold et al. 1995). Since undisturbed, stable rivers are known to have channel configurations that are proportional to the size of the upstream watershed, discharge, and sediment load, regression analysis can be used to develop regional curves that predict channel response within various watersheds. To create this predictive tool for the Upper Menominee River watershed, regional curves were developed that regressed drainage area to bankfull discharge, width, depth, and cross-sectional area. Correlation coefficient values, R^2, measured the fit of the regional curve data to the regression line. The R^2 values for the Upper Menominee River regional curves indicate that bankfull discharge has the weakest relation to drainage area. This variability may be a result of visually estimating bankfull stage, while all other variables are measured. In contrast, bankfull cross-sectional area and depth have the strongest relation to drainage area as evidenced by R^2 values of 0.78 and 0.74, respectively.

Federal, state, and local agencies are increasingly undertaking channel improvement projects on Michigan's streams and rivers. In most cases, such projects are initiated without knowledge of either the historical morphology of the stream channel or the difference between current and pre-development conditions. The regional curves developed for the Upper Menominee River can be used to facilitate interpretation and design of stream restoration projects and assess stream health. The results of this study should serve as a general guide for identification of bankfull channel dimensions at un-gaged reaches. Additionally, the relationships developed in this document provide preliminary design parameters for streams with similar characteristics. However, there are limitations when using this information in designing channel improvement projects. Since the sample size is small and represents a limited range of stream types, these data should be used only for general guidance and design. Finer scale aspects of channel improvement design should come from appropriate reference reaches that closely match the conditions of the desired project reach.

Michigan's Stream Team is scheduled to collect additional data throughout Michigan in 2007 and 2008 for development of statewide regional curves. For more information and to follow the status of the data collection, see http://www.michigan.gov/streamteam.

Acknowledgments

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Glossary

Bankfull channel- The area of the channel formed by bankfull discharge.

Bankfull cross-sectional area- The area of the bankfull channel measured along a vertical plane perpendicular to the stream to determine channel form.

Bankfull discharge- The streamflow at which channel maintenance and movement of bedload sediment are most effective. The bankfull discharge corresponds to bankfull stage.

Bankfull mean depth- The mean depth of the bankfull channel measured perpendicular to the streamflow.

Bankfull width- The width of the bankfull channel measured along a vertical plane perpendicular to the stream.

Drainage area- The area, measured in a horizontal plane, enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into the stream above the specified point.

Flood-prone width- The width of a surface perpendicular to the channel at an elevation that corresponds to twice the maximum depth of the bankfull channel. The flood prone width corresponds to elevations of relatively frequent floods (< 50 year recurrence interval).

Regional curves- Regressions of the relation of bankfull channel characteristics to watershed drainage areas. Regional curves are a common tool for defining bankfull characteristics without additional data collection or analysis, and for estimating bankfull channel dimensions and discharge at un-gaged reaches within the same watershed or within watersheds having similar characteristics.

Stream reach- A section of stream that met the minimum criteria of having at least 10 years of U.S. Geological Survey gage station record, a recoverable benchmark referenced to gage datum, no influence by dams or artificial control structures, and the ability to be safely waded for a length of 20 bankfull widths or two meanders.

Stream restoration- The adjustment of stream dimension, pattern, and profile to a condition where it effectively accommodates a range of streamflow and sediment and supports diverse habitat.

Watershed- For this report, used interchangeably with drainage area.

References

Dunne, T., and L. B. Leopold. 1978. Water in environmental planning. W. H. Freeman and Company, San Francisco.

Emmett, W.W. 1975. The channels and waters of the Upper Salmon River area, Idaho. U.S. Geological Survey Professional Paper 870-A., Washington, D.C.

Leopold, L.B., M.G. Wolman, and J.P. Miller. 1995. Fluvial processes in geomorphology. Dover Publications, New York.

Michigan Department of Environmental Quality. 2006. Peak flow analysis of Michigan USGS gages. Internal report, Lansing, Michigan. Available: http://www.deq.state.mi.us/documents/deq-lwm-hsu-nps-2005-qpeak.pdf. (January 2007).

Michigan's Stream Team. 2005. Protocol for field surveys of stream morphology at gaging stations in Michigan. Internal report, Lansing, Michigan. Available: http://www.deq.state.mi.us/documents/deq-lwm-nps-mi-field-survey-protocol.pdf. (January 2007).

Rosgen, D. L. 1994. A classification of natural rivers. Catena 22: 169-199.

Rosgen, D. 1996. Applied River Morphology, 2nd Edition. Wildland Hydrology, Pagosa Springs, Colorado.

Wisconsin Electric Power Company. 1999. Draft environmental assessment- Upper Menominee River Basin hydroelectric projects, Milwaukee.

Wolman, M.G. 1954. A method of sampling coarse river-bed material. Transactions of American Geophysical Union 35: 951-956.